A New Method of Personalized Training of Logging Machine Operators

LIUDMILA STESHINA
Department of Radio Technical Volga State University of Technology
Yoshkar-Ola
RUSSIA
Steshinala@volgatech.net

IGOR PETUKHOV
Department of Radio Technical Volga State University of Technology
Yoshkar-Ola
RUSSIA
Petuhoviv@volgatech.net

IILYA TANRYERDIEV
Department of Radio Technical Volga State University of Technology
Yoshkar-Ola
RUSSIA
TanryverdievIO@volgatech.net

PAVEK KURASOV
Department of Radio Technical Volga State University of Technology
Yoshkar-Ola
RUSSIA
KurasovPA@volgatech.net

ANDREY GLAZYRIN
Department of Radio Technical Volga State University of Technology
Yoshkar-Ola
RUSSIA
GlazyrinAE@gmail.com

Abstract: - The paper presents a new method of personalized training for an operator. The method based on mathematical model of interaction between an operator and production equipment and offers an evaluation for a person's rate of making an operating decision. The key idea is to define typical acts of logging machine operator. The defined acts are presented in form of special test, which represents a simplest task. The training process is described through three main steps: watching, recalling and doing (WRD). In this case, the task result is time delay for motor and sensory layers as in real professional case. The model of interaction between operator and production equipment is represented in form of transfer functions. The transfer functions are a sequence of connected standard dynamical elements, which include a rate of information perception and decision making, and the means accuracy of controlling actions. The imitation model shows that during four seconds of the control action the beam moved by 1.281 m and a delay of the beam movement start after the control signal start for 0.578 sec. Therefore quality of operator's control is definitely determined by the following parameters: a time constant that means a response time of a neuromuscular system and human adaptive abilities and describes a rate of control action development; a ratio of human internal feedback and describes accuracy of the control action development; and an operator's response delay time.

Key-Words: Man-machine systems, Industrial Control, Automatic Control, Machine, Operator, Performance, Harvester, Simulator

Received: January 11, 2020. Revised: April 9, 2020. Accepted: April 20, 2020. Published: May 4, 2020.

1 Introduction

Man-machine system (MMS) usually refers to a system including a person or group of people interacting with production equipment and involving information processing and controlling production of material assets. When evaluating reliability of technical objects, modern researchers introduce a notion of an ergatic control system (ECS) which, in addition to a technical system as it is, includes persons interacting with this system. The main function of a person in the ECS is complex system control; and in this contexts, optimal distribution of functions between an operator and a technical device as well as their mutual complementation should be also taken into consideration. A standard model of an ergatic system can be represented as objects interacting between each other. In this case, a person is a certain operator having a set of specific dynamically changing skills, working experience, psycho-physiological parameters and individual features, and a working environment is some collection of external and internal factors that make an impact on functioning of the ECS objects.

A necessity for building a model of the MMS functioning appears within many processes aimed at investigating, designing and testing such systems. An approach, which considers a person to be the main element of a control chain, represents them as functional behavior models demonstrating stages of the operator's activity. The operator's actions are combined into the general succession of elements that make it possible to build a united logical and temporal sequence from independent basic functions, such sequence is tolerant to disturbances and ensures attaining a purpose of its functioning [1]. The models used for studying operator's activity can be represented as regression models, algebraic systems of equations, Markov and semi-Markov processes, models based on the theory of queues, logical automation, formal grammars, logical and flow-graphs, Petri nets, logical-linguistic models of situational control, Yanov schemes, Lyapunov algorithms, linguistic algebraic systems, precedence networks, critical path method networks, combination of E-networks with an evaluating method of piecewise linear automaton, probabilistic algorithmic function network, functional and functional semantic networks. Nowadays we know numerous models of professional activity of an human-operator [2, 3], however E. Hollagel [4] states that it is necessary to refuse from a concept of analysis of individual operator's actions in favor of a model of joint performance of a person and a machine. A common drawback of the known models of man-machine systems is their pursuing for description of actions, information flows and connections in the systems that is definitely necessary for building a training process of operators' professional activity and developing professional skills of production process control in general, but it doesn't ensure analysis of professionally important qualities (PIQs) that make an impact on the MMS efficiency during individual operations included into the control process.

The rest of the paper is structured as follows. Section 2 describes the main problems of performance for man-machine systems and operator’s role. Section 3 covers
model for evaluation of operator’s skills based on a rate of information perception and decision making. Section 4 mentions a method for evaluation of operator's professionally important qualities. Section “Conclusion” concludes this paper and presents future works based on the mentioned research.

2 Performance of Man-Machine Systems And Operator’s Role

It is convenient to consider the performance of man-machine control systems on the example of a logging process. In this case, the MMS model includes an operator, production equipment (a harvester) and the environment (a forest stand) that interact according to the certain technology (Fig. 1).

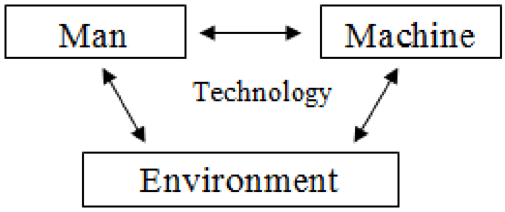

Fig.1 The MMS model

Analysis of this model shows that an operator receives information through two parallel channels: a channel of interaction with the environment and a channel of interaction with a machine.

It is proper for an experienced operator of a harvester to perform stages of operator's activity successively [5]. Because of operators' insufficient professional training or their insufficient working experience it is possible to return to a previous stage of the operator's activity or to recur due to previous faulty actions. For instance, faulty direction of work tools of a harvester at the tree or faulty positioning (Fig. 2) of work tools of a harvester in relation to the tree cause multiple repetitions of this action with the aim of correcting their position.

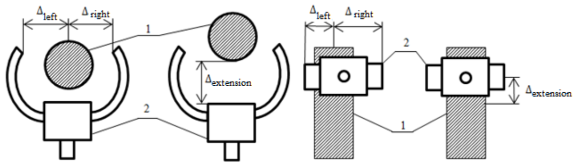

Fig. 2 Faulty positioning of harvester work tools in relation to the tree

Faulty positioning of harvester work tools in relation to the tree results in a significant decrease in efficiency of the harvesting process in general; and particularly, quality of the logging products degrades and the harvesting equipment breaks down due to high loads on components and assemblies. Displacement of a harvester head during tree getting to the left or to the right from the vertical axis of a growing tree causes an extreme pressure of pinch rollers on the tree, it results in mechanical damage of logged wood as shown in Fig. 3.

Fig. 3 Mechanical damage of wood in result of faulty positioning of harvester work tools

One of the main reasons of situations connected with operator's faulty actions is operator's insufficient training and little working experience. H. Koivo and K. Tervo [6, 7] note that operator's performance strongly correlates with their working experience and professional skills. There is evidence that differences in the performance of beginners and professional operators during powered timber harvesting make about 40%. In addition, the quality of logging also differs greatly [8]. F. Purfürst [9] analyzed learning curves of 32 harvester operators during three years (0.65 mln cubic meters of logged timber), 16 of them were new harvester operators. The analysis of operators' performance shows that most operators begin their career with middle performance from 50% to 60% and double their performance (200%) by the end of the learning phase. In this case, the learning curve corresponds to a sigmoid model. Reduction of productivity by 24% at the learning phase were calculated for the average durability of eight months, it corresponds to approximately 45,000 Euro.

Kirk P. [10] states that a skilled operator is the most advantageous investment by a timber procurer. A replacement of an experienced operator by a beginner results in losses of about 49,650 Euro until the latter gains a necessary experience as well as in additional expenses on training (about 15,000 Euro) [11]. On average, the difference of performance between an experienced operator and a new one is 2:1 [12], and it is most notable within first 30 working days of a new operator. Performance improvement, in its turn, depends on many factors. Heinimann found that working with trees of small diameter a harvester operator improved their performance during a year only by 50% [13].

Researchers describe gaining a necessary experience using machine-hours (from 1,000 to 1,500) [14] or adaptation time (from 8 to 12 months) [15]. It is proved that a clearly structured training program reduces duration of the learning curve [10]. In case of re-training when an experienced operator changes a type of logging machine, the adaptation time is about 20 days [16].

3 Evaluation of Operator Skills

An essential principle of skill evaluation is Fitts' approach which describes correlation between an index of performance and an index of difficulty [17]. Fitts' law is a mathematic ratio which models correlation of speed and accuracy of human rapid movements such as manual control of a work tool that starts at the certain place and transition of it to a target area [18].

In case of control according to one coordinate a movement time (MT) of the work tool being at the distance A (Fig. 4) to the work area with the width W can be defined by Eq. 1 [19], where a and b (intercept and slope) are empirical interface constants obtained by linear regression, and c is a constant of fixed value (0, 0.5 or 1). 1/b is the index of performance:

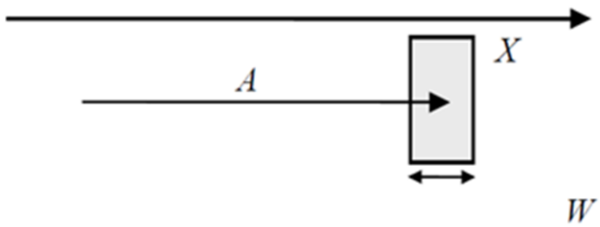

Fig. 4 The diagram of work tool direction on one coordinate

$$MT = a + \log_2(\frac{2A}{W} + c) \qquad (1)$$

The index of task difficulty (ID) is defined as follows:

$$ID = \log_2(\frac{2A}{W} + c) \qquad (2)$$

The process of work tool direction requires a high accuracy of operating in the conditions of restricted visibility (that is noisiness of the visual control channel) as well as development of operating skills taking into account dynamic parameters of the production equipment. Most production machines (like harvesters, forwarders, feller bunchers) have a double-axis joystick manipulator as a device for interaction with an operator. Such manipulators can be both hydraulic and electric ones when electronic control devices are applied for hydraulic solenoid valves.

An operator developing a complex sensomotor reaction [20] of the visual-motor tracking for direction of production equipment manipulates the joystick handles by declining them on the horizontal and vertical axes from the central zero position. The input manipulation on the joystick is moving of a handle in relation of its central zero position on the axis. The output response of the joystick, in case of a hydraulic manipulator, is a value of hydraulic valve

The process of work tool direction requires a high accuracy of operating in the conditions of restricted visibility (that is noisiness of the visual control channel) as well as development of operating skills taking into account dynamic parameters of the production equipment. Most production machines (like harvesters, forwarders, feller bunchers) have a double-axis joystick manipulator as a device for interaction with an operator. Such manipulators can be both hydraulic and electric ones when electronic control devices are applied for hydraulic solenoid valves. An operator developing a complex sensomotor reaction [20] of the visual-motor tracking for direction of production equipment manipulates the joystick handles by declining them on the horizontal and vertical axes from the central zero position. The input manipulation on the joystick is moving of a handle in relation of its central zero position on the axis. The output response of the joystick, in case of a hydraulic manipulator, is a value of hydraulic valve capacity. In case of an electric-driven manipulator, the output response is a value of an electric parameter (usually electrical resistance) controlled by the joystick.

Mathematical representation of an operator in the transfer functions can be built as a sequence of connected standard dynamical elements (Fig. 5), where the element $W_1(s)$ means a rate of information perception and decision making, and the element $W_2(s)$ means accuracy of controlling actions.

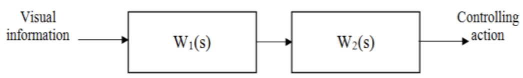

Fig. 5 Representation of an operator in the transfer functions

K. A. Pupkov [21] offers an approach to the modeling of human-operator's dynamic properties using a non-linear element. This proposal is based on the experimental data obtained by the researcher who shows operator's transfer functions as follows:

$$W_{op}(s) = \frac{K(T_y s+1)}{T^2 s^2+2\xi T s+1} e^{-\tau s} \quad (3)$$

where K= 0.33 is an amplification factor; τ = 0.16 is an operator's delay time which describes a human capability to perceive a variation rate of a controlled value; T = 0.4 is a time constant that means a response time of a neuromuscular system and human adaptive abilities; ξ = 0.6 is a parameter that means a ratio of human internal feedback (an analyzer loop); Ty = 0.36 is an operator's look-ahead time.

A mathematical model of operator's activity in mechanized timber logging is built on the model of visual-motor tracking and the known transfer functions of a human-operator.

In order to model elements of the direct loop and the feedback loop of the model shown in [22]. We use a proposal by V.A. Trapeznikov on evaluation of information processing by an human operator [22]. Within this approach the quality of operator's work has exponential dependence on the training time. Then, we can represent a transfer function as follows:

$$W_{k1}(s) = \frac{K_1}{T_{k1}s+1}, \quad (4)$$

where K_1 is an element amplification ratio; T_{k1} is a training time constant.

The total transfer function of operator's activity taking into accout (3), (4) will be equal to:

$$W_{tot.}(s) = \frac{KK_1(T_y s+1)}{(T^2 s^2+2\xi T s+1)(T_{k1}s+1)} e^{-\tau s}. \quad (5)$$

Substituting the transfer function of operator's activity in the mathematic model of the production equipment we obtain a mathematic model of logging machine equipment control, this model is implemented in the Simulink environment and its structure is shown in Fig. 6.

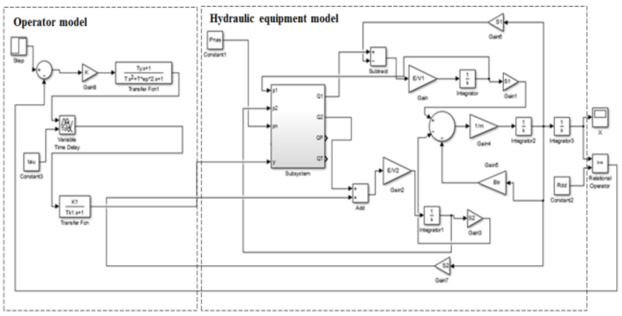

Fig. 6 shows the outcome of the simulation modeling of logging machine equipment control in the Simulink environment.

The upper diagram represents extension of the forwarder beam and the lower diagram - a control signal setup by an operator. The diagram shows that during four seconds of the control action the beam moved by 1.281 m. The diagram also shows a delay of the beam movement start after the control signal start for 0.578 sec. Thus, on the basis of the mathematical model of the logging machine equipment control we can conclude that the quality of operator's control is definitely determined by the following parameters: T is a time constant that means a response time of a neuromuscular system and human adaptive abilities and describes a rate of control action development; ξ is a parameter that means a ratio of human internal feedback and describes accuracy of the control action development; and τ is an operator's response delay time.

4 An Approach for Evaluating the Operator's Performance

Therefore, each operator action may be presented in form of sensor-motoric reaction. Firstly, the operator watches currently situation, which is related to orientation and adaptation during training. Before training acts the operator makes a decision based on recalling a previous experience, how he/she will do the task more efficiently. Finally, operator uses motor program for current task. Therefore, we have three main steps in training process: watching + recalling + doing (WRD).

The key idea of WRD approach is the decomposition of sensor-motoric process into three layers. The sensory layer (watching) covers visual capturing of important information from environment. After the accumulation of important information occurs the querying to knowledge base (recalling) for decision-making in current situation. This process is performed on cognitive layer. If knowledge base contains same professional case then scheme of motor reaction (doing) is retrieved. In the same time, if knowledge base doesn't contain current professional case then knowledge base is saturated an unknown situation. Finally, operator activates motor program based on decision-making in current situation from cognitive layer, Fig.7.

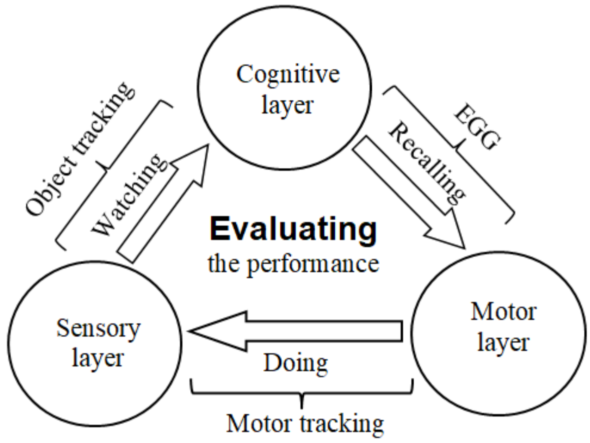

Fig. 7 The diagram of the developed test method

Thereby, for WRD approach the performance during training session is summarized from performance of each layer. For example, motor or sensory layers may be evaluated using special tests, which activate the sensor-motoric reaction for the appropriate operator task. The evaluating the performance on the cognitive layer is important step in WRD approach, because continuous brain activity may result the tension and fatigue. Therefore, it needs to measure the brain activity with EEG during executing tests on sensory and motor layers.

We believe the brain activity in training sessions should rise because it is important to accumulate new training cases. The brain activity in control sessions should fall because it indicates knowledge base is saturated. The continuous generation of training case may help to saturate the knowledge base. Therefore, the fuzzy model based on the generation of training cases was developed. The key idea is the changing complexity of tests. The comparison based on WRD approach. Moving object and motor tracking (rejection from horizontal and vertical axes) were selected.

5 Evaluation Method of Operator's Professionally Important Qualities

There are many evaluation methods for performance of operator, but a few methods include operator reaction. The operator reaction is important professional capacity to pass a decision during the working procedure. In this case, we can create a toy task in form of special test. This task has to copy the main principles of operator actions like in a real professional case. Therefore, the result may be presented time reaction or quality of manipulation. Let define the T, ξ and τ parameters for special test.

The developed method implies that a trainee sees a circle on the computer display, this circle is a limiting field inside of which a round-shaped test object is placed, Fig.8.

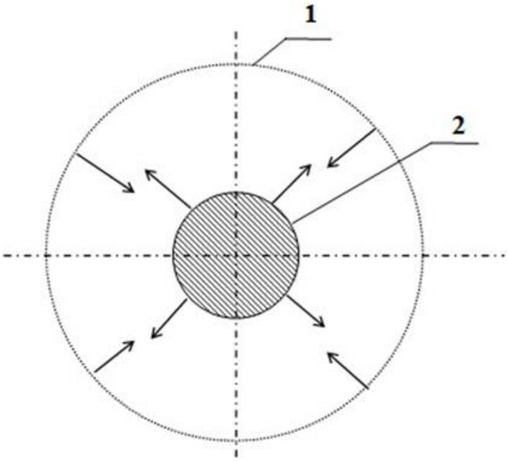

Fig. 8 The diagram of the developed test method

The test object is increasing and the closed circle is decreasing in diameter with the setup speed, at the same time the test object simulates its movement toward the testee. At the moment when a person believes that the size of the limiting closed circle and that of the test object coincide, the testee presses a button on the panel, and the objects stop moving. Then, an uncoincidence error of the test object and limiting circle diameters is calculated, it will be considered to be a lag error time (with a positive sign) or a look-ahead error time (with a negative sign). At the next stage a response time *Tp* (when a person is reacting to a moving object) is calculated as an average value according to the formula:

$$T_p = \frac{\sum_{i=1}^{n} t_i}{n} \qquad (6)$$

where t_i is the i^{th} uncoincidence error of the circle and object, ms; n is a number of stops of a point object during testing. In a preset time a testee is again presented these objects in their initial sizes and the test is repeated several times as prescribed.

Boundary conditions of the test outcomes of a time constant that means a response time of a neuromuscular system and human adaptive abilities and describes a rate of control action development are obtained from the mathematic model of operator's activity. These boundary conditions may be represented as a fuzzy logic model with one input variable, that is a rate or control action development and three linguistic variables: low, normal, high.

4 Conclusion

Thus, evaluation of the operator's control action development rate makes it possible to build a personalized approach to the training of logging machine operators. The proposed scheme of the professional training process for logging machine operators with numeric analysis [23] involving simulators is shown in Fig. 9.

The peculiarity of this scheme is that a low initial level of the absolute professional aptitude (Group 1) intends first of all development of the professionally important qualities using appropriate exercisers. Otherwise, as the practice proves, these trainees cannot develop professional skills and are dismissed. Development of PIQs help trainees to go to a more complicated stage of training, that is study of logging machine operation using simulators.

It should be noted that a total period of the professional training process for each group of trainees is the same, only durations of individual modules vary.

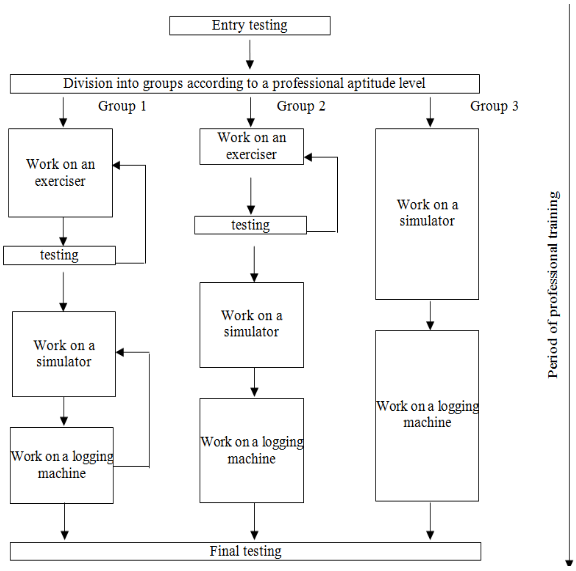

Fig. 9 The scheme of the professional training process for logging machine operators

Further research work should be focused on the experiments based on mentioned model and be used for new model [24]. It should be noted the experiments are related to the tests, which are described typical model of reaction for operator and activate motor and sensory layers as in real professional case. Moreover, the fuzzy logic model will be used for the developed test method. The mentioned approach may help to evaluate training program with evaluating sensory, cognitive and motor layer without developing prototype training simulator.

Acknowledgments

The results of this study were obtained with the support of Grant No. 25.1095.2017/4.6.

References:

[1] Sergunova O.V., Pavlenko M.A., Timochko A.I., Vorobev E.V., Analysis of modeling methods for operator activity, The human-machine system in Information Processing Systems, 2015, 7 (132) , 80-82. (In Russian)

[2]Shibanov G. P., Analysis of the interaction of the components of the system “pilot - aircraft - medium”, Flight, 2012, no. 4 - 3, pp. 8.(In Russian)

[3]Braginsky M. Y., Burykin Y. G., Tarakanov D. V., Modeling of human-machine systems taking into account the influence of light stimuli on a human operator, Bulletin of Cybernetics, 2016, no. 1, pp. 63-73.

[4] Hollangel, E. Human reliability assessment in context, Nuclear engineering and technology, 2005, Vol.37, no.2,pp. 159 – 166.(In Russian)

[5]/ K. Tervo, L. Palmroth, H.Koivo Skill evaluation of human operators in partly automated mobile working machines, IEEE Transactions onautomation science and engineering, 2010, Vol. 7, no. 1, pp. 133-142.

[6] Tervo K., Koivo H. Towards human skill adaptive manual control, International Journal of Advanced Mechatronic Systems, 2010, Vol. 2, no. 1-2, pp. 46-58.

[7] Tervo K., Rohilla A. Recursive tuning algorithm for assist controller of a trolley crane system, Applied Machine Intelligence and Informatics(SAMI), 2011 IEEE 9th International Symposium on, 2011, 61-66

[8] H. Ovaskainen, J. Uusitalo, and K. Väätäinen, Characteristics and significance of a harvester operators’ working technique in thinnings,Int. J. Forest Eng.,2004, vol. 15, no. 2.

[9] Purfürst F. T. Learning curves of harvester operators, Croatian Journal of Forest Engineering: Journal for Theory and Application of Forestry Engineering, 2010, T. 31, no.2, pp. 89-97.

[10] Kirk, P., Byers, J., Parker, R., Sullman, M. Mechanisation Developments within the New Zealand Forest Industry,The Human Factors. International Journal of Forest Engineering, 1997, no. 8(1), pp. 75–80.

[11] Gellerstedt, S., Liden, E., Bohlin, F.Health and Performance in Mechanized Forest Operations, Swedish University of Agricultural Sciences, 2005, pp. 45

[12] Stampfer, K., Gridling, H., Visser, R. Analyses of Parameters Affecting Helicopter Timber Extraction, International Journal of Forest Engeneering, 2002, no. 13(2), pp. 61–68.

[13] Heinimann, R., Lerning curve effect of harvester operators, Unpublished Technical report, Department Wald und Holzforschung, Professur forstliches Ingenieurwesen, ETH Zürich.

[14] Gabriel, O. Harvester operator for Stendal, Forst & Technik, 2005, no. 17(3), pp. 26–27.;

[15] Loschek, J., Jirikowski, W., Pröll, W., Sperer, S., Tresniowski, S.Wood in thinning, Kooperationsabkommen Forst-Platte-Papier, 1998, 120 p.

[16] Von Bodelschwingh, E., Pausch, R., VALMET 801 combi – first operational test results, AFZ-Der Wald, 2003, no. 17, pp. 858–860.

[17] P. M. Fitts and J. R. Peterson, Information capacity of discrete motor responses,J. Exper. Psych., 1964, vol. 67, no. 2, pp. 103–112.

[18] P. M. Fitts, The Information Capacity of the Human Motor System in Controlling the Amplitude of Movement, Journal of Experimental Psychology: General, 1992, vol. 121, no. 3, pp. 262-269.

[19] Antunes R., Coito F. V., Duarte-Ramos H. Skill evaluation in point-to-point human-machine operation, Applied Mechanics and Materials, 2013, T. 394, pp. 463-469.

[20]Petukhov, I. V. Decision support system for assessing the professional suitability of the operator of ergatic systems (using transport and technological machines as an example),Abstract of a dissertation for the degree of Doctor of Technical Sciences, 2013, pp. 32. (In Russian)

[21]Pupkov K.A., Ustyuzhanin A.D. Identification and assessment of training in dynamic human-machine systems, Vestnik MGTU im. N.E. Bauman. Ser. Instrumentation, 2003, no. 4, pp. 95-103.(In Russian)

[22] Trapeznikov, V.A. Man in the control system, Automation and Telemechanics, 1972, no 2, pp. 5 - 16. (In Russian)

[23] Guessab A., Aris A., Numerical Analysis of CPU with Heat Sink base of Copper Core using CFD, International Journal of Mechanics, pp.144-148, Volume 13, 2019

[24] Ziad Shakeeb Al Sarraf, Design and Analysis of Ultrasonic Horns Operating in Multiple Vibration Modes International Journal of Mechanics, pp.129-132, Volume 13, 2019